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During the Blue Nile Campaign in Egypt, the Roman Army received a new issue of arbalest, a kind of super crossbow, which was used to throw huge stones. Because of its size this weapon was operated by a crew of men. When these new weapons were placed into service, the pentle hooks on the onagers of the arbalest (literally the "kicker" or catapult of the weapon) broke, causing tragic injuries to the arbalest crews. It was found that severe corrosion was causing the breakage. Seneca, General of the Roman Army in Egypt, sent this report to his higher command:

> "The pentle hooks on the onagers are weakened so badly by corrosion that the arbalests are causing more casualties in our own army than to the enemy."

Corrosion is not a problem that is new, nor is it peculiar to the Air Force. In the past the Armed Forces have considered corrosion to be a nuisance--more detrimental to the aesthetic aspects of their resources than to the utility of their weapons.

And, until recent years, corrosion was not considered to be a serious problem in the Air Force. The C-47 is an outstanding

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example of Air Force equipment which has been only mildly affected by corrosion. This aircraft was constructed of nearly pure aluminum and built to withstand stresses far in excess of those normally encountered. Many of these "old birds," with thousands of hours of airframe time, are still operating reliably in all parts of the world.

But, as science and engineering advanced the state of the art, aviation moved into a new domain of performance where tremendous payloads, speeds, aerodynamic stresses and temperature changes exist. New and sophisticated alloys with a high weight-to-strength ratio have been and are being developed to meet the ever-increasing demand for higher performance aircraft. Airframes have been developed to much closer tolerances to meet this demand for increased efficiency and performance.

But these new and sophisticated alloys seem to have less tolerance for corrosion, or they are more susceptible to corrosion. And today corrosion is one of the major problems facing the Air Force.

To address this subject, corrosion should be defined: It is the deterioration of the boundary layer between the granular structure of metal, or, corrosion is intergranular.

At this point I must introduce another term, "fatigue," so that we may distinguish between the terms corrosion and fatigue. Fatigue is cross granular cracking. In nearly every case where metal fatigue has been a problem, there is some evidence of intergranular corrosion in conjunction with the fatigued area.

What causes corrosion? Thousands of words have been written on this subject--so to avoid a long-winded dissertation on the cause of corrosion, let me define it as oxidation of metal as a direct result of electrolytic action. To induce oxidation or corrosion, three conditions must exist:

1 - Unprotected metal

2 - An ionic conductor: i.e., salts, chemical dust, a dissimilar metal condition, etc.

and 3 - Water or a medium through which electrons can flow

What Are the Types of Corrosion? Corrosion is like crime--it comes in many forms, all of which are bad; it is also like cancer and serious corrosive conditions can develop from the most simple form of surface corrosion or a microscopic abrasion in a metal surface. I will not give an extended discussion on the kinds of corrosion, but will limit my comments to just four types.

1. Exfoliation Corrosion: This generally results from dissimilar metals or bimetals in contact. I want to emphasize dissimilar metal as distinguished from bimetal. The dissimilar metal problem can develop at a joint of two like metals which are unprotected or around a rivet. Exfoliation is a laminar type of corrosion that usually causes extensive damage before it is apparent and can be detected.

2. Pit Corrosion: This corrosion is usually found on skin surfaces. It is caused by a break in the protective surface or protective coating. This type of corrosion spreads laterally below the surface and around the pit, in the form of intergranular and exfoliation corrosion.

3. Intergranular Corrosion: This starts from a break in the protective surface or from a microscopic crack and weakens the boundary layers between the metal grains and, in turn, weakens the tensional strength of the affected area.

4. Stress Corrosion: This is corrosion in its most insidious form. It is found in the stress areas, and can result from dissimilar granular structure that occurs within the metal during the heat treatment, or hardening processes, or from microscopic cracks. This "locked-in stress," as it is called, weakens an area and causes that area to be highly susceptible to fatigue. Often spars, struts and empennage sections explode into disaster at the slightest provocation due to locked-in stress and fatigue.

Can corrosion be eliminated? The answer to this question is no. There has been no breakthrough in the development of metals that are immune to corrosion. But corrosion can be minimized and controlled.

What has been done to minimize corrosion? Let me start with the design specifications for weapon systems. These are very specific in the precautions that must be taken in the design of a weapon system to minimize corrosion. These specify:

protective coatings

painted interior surfaces

alclad surfaces (minimum effective thickness .020)

wet riveting

sealing of raw seams

sealing between joints

protection between dissimilar metals, etc.

<u>Production specifications</u> firmly establish the precautions that must be taken to minimize corrosion. Here I would like to point out the classifications of corrosion protection required in MIL-F 7179A. There are three classes specified.

Class I — Gives maximum protection and is the required protective coating for systems which will be continuously exposed to corrosive elements.

Class II — Gives adequate protection for systems which will be based and operated in a corrosive environment.

Class III — Provides only minimum protective measures; for inland-based systems not to be operated in a corrosive environment.

In spite of the fact that the Air Force is a global force, operating in every climatic environment, the F-111 (TFX) is the first Air Force aircraft to be manufactured with Class II corrosive protection required in the design and procurement specifications. All others have been built with Class III corrosion protection. The C-141 production specifications were changed from Class III to Class II only last year following the devastating corrosion damage found in the C-130's in the Pacific.

Within the Air Force there are hundreds of examples where simple precautions to minimize corrosion have been ignored in the design, procurements, and construction of our weapons systems, either through ignorance, neglect, or for the sake of minor economies that have later resulted in enormous cost in lives, equipment and money.

At this point I would like to correct a statement I made at the start. I said, "In the past our Armed Forces have considered corrosion to be a nuisance, more detrimental to the aesthetic aspects of their resources than to the utility of their weapons."

This statement is not true of the United States Navy. In its operational environment, the Navy has been forced to recognize corrosion and it has an effective corrosion protection and prevention program in being and enforced.

In spite of this excellent corrosion program, the Navy estimates the cost of corrosion in the air arm to be in excess of $600 million annually. Our look at corrosion costs to Air Force resources has been very limited to this point, but there is every indication that the cost of corrosion to the Air Force will exceed a billion dollars annually. An adequate corrosion program would cost only a fraction of that amount.

<u>What is necessary to insure an effective corrosion control program?</u>

1. Recognition of corrosion as a major problem at "top side" in DOD and USAF.

2. Trained engineers to insure compliance with existing design, procurement, production, modification and maintenance directives at all levels.

3. Eliminate the small economics in procurement and production that later develop into costly maintenance and modification requirements.

4. Provide for and enforce proper cleaning and protection of weapon systems and ground support equipment in the field.